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A Forward Looking Detector for the DØ Area

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SUMMARY

We propose a charged-particle magnetic spectrometer for the TeV I $p\bar{p}$ collider in the DØ collision region. It consists of four 0.5 x 0.5 x 1 m. dipole magnets, with tracking chambers, cluster counting transition-radiation detectors and electromagnetic calorimeters for momentum measurement and particle identification. The coverage is 360° in azimuthal angle and ~ 5 mrad to ~ 50-100 mrad in polar angle. The physics goals complement those of the CDF, and cover a broad variety of low-to-intermediate $p_{\perp}$ studies in the 50% of the phase space inaccessible to typical central detectors.

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INTRODUCTION

Long ago it was believed that all important strong-interaction physics was contained in low-$p_\perp$ processes. This point of view has changed, and hard-collision phenomena now dominate the attention of experimentalist and theorist alike. But there is still important physics contained in soft-collision phenomena.

With the large emphasis on high-$p_\perp$ processes in the CDF detector design, it is natural to expect a complementary emphasis on soft collisions in the proposals for the DØ interaction region at the TeV I collider. The CDF detector does not cover angles much below ~ 100-200 mrad, i.e. at most ± 3 units of rapidity. On the other hand, there can be expected to be copious particle production down to angles $\lesssim$ 1 mrad, or ± 7 units of rapidity. More than half the invariant phase space is not covered.

There do exist proposals for looking at elastic scattering with "Roman pots", as well as a proposal (P-704) for looking at the missing forward phase space with calorimetry and tracking. But it is surprising that there is no proposal for a charged-particle magnetic spectrometer for detailed study of the forward phase space.* It is our purpose to ameliorate this situation. We suggest that the angular

*Such a "proposal" does exist for ISABELLE. See BNL51443 (Isabelle 1981 workshop proceedings), Vol. 2, p.426 (S. Lindenbaum and R. Longacre).

range of ~ 5 mrad to ~ 50-100 mrad can be studied in detail, with momentum analysis, and with particle identification provided via cluster-counting transition-radiation detectors. Electron and photon detection are provided with electromagnetic calorimetry placed on magnet faces and downstream of the spectrometer. The apparatus is modular with considerable amount of free space between elements. This should allow flexibility and the opportunity to augment the basic system as the evolving physics warrants.

The detector layout is shown in Fig. 1. Four identical 1.5 Tesla dipole magnets of 50 x 50cm aperture and 1m length provide $p_{\perp}$ kicks of 4 x 0.5 GeV. The 1 TeV Saver beam suffers a parallel deflection of ~ 3mm by the first pair of magnets, and is deflected back onto the closed orbit by the second pair. We have chosen multiwire proportional chambers for the tracking, although such a choice is not an imperative. Cluster-counting transition radiation detectors provide π/K separation at energies ~ 50-200 GeV, well matched to the expected spectra.

The spectrometer does not quite fit into the existing main-ring tunnel. The apparatus does fit underneath the main ring beam pipe. A deepening of the tunnel by ~ 1-2 ft. is required to comfortably fit in the magnets and not to compromise the physics goals. The spectrometer length (25m) is chosen so as not to interfere with the Saver lattice.

The cost of the facility is probably controlled by the tracking chamber electronics, which in turn depends upon how much momentum resolution and redundancy for pattern-recognition is desired. A crude estimate of $2-3M for the initial system should be adequate for the first round of exploratory physics. This does not include the extra civil construction costs associated with the tunnel enlargement.

PHYSICS

The basic architecture of the spectrometer allows detection of charged particles and momentum measurement in an angular region of $\sim$ 3 mrad to $\sim$ 62 mrad ($\Delta y \simeq 3.0$) with full azimnthal coverage. If the (upstream) magnet surfaces and far downstream aperture are covered with electromagnetic calorimeters, then angular coverage for e/γ is $\sim$ 3 mrad to $\sim$ 250 mrad ($\Delta y \simeq 4.5$) Some muon detection could be provided over this range as well by utilizing the iron return yokes.

Evidently almost all of the phase-space covered by this detector is not accessible even to the CDF forward detector. It would seem imperative that a strong effort be made to explore this region with a spectrometer capable of momentum measurement and as much particle identification as possible. The modular nature of the apparatus and the free space available between magnetic elements would allow staging the apparatus construction to emphasize those physics issues most topical at the time of TeV I commissioning, as well as to exploit new technical innovations.

A typical menu of measurements might be (in rough chronological order):

1) <u>Search for new relatively long-lived particles</u>:

We will be sensitive to new particle decays which occur between 1 and 15 m from the primary interaction vertex. If the new-particle path length is greater than 1 m, we should in many cases be able to identify the presense of a second vertex. The vertex may even be visible if the particle were to decay in the spectrometer. Decays after about 15 m would not be accessable to the spectrometer. Fig. 2 shows the region of mass and lifetime accessible to us. The cross-section limit is probably constrained not by luminosity but by the data aquisition system. A cross section limit of $\lesssim 10^{-31}$ cm^2 may be reasonable.

While the mass scale (5-30 GeV) appropriate for a search using this detector is not extraordinarily large, one must keep in mind that

A) The new particle may be a decay product of a heavier system which can only be produced at the Tevatron energy scale. Recall that the increase in available energy relative to the SPS collider is equivalent to the increase of available energy from the AGS to the FNAL machine.

B) There has been reported evidence for delayed particles ($m \gtrsim 5$ GeV? $\tau \gtrsim 10^{-9}$ sec?) in air showers (Goodman,1979)

2) <u>Inclusive hadron spectra</u>:

The projectile fragmentation region is an obvious region of interest to study with this detector. The region

$0.05 < x < 0.3$ would contain the meson fragments: i.e. $20 < p < 300$ GeV. For baryons, one would like to study the spectra up to large x (300GeV<p<1 TeV), which in this spectrometer is only accessible at rather large (but still attainable) $p_\perp$ of order 1.5 -5 GeV. In Fig. 3, we show the inclusive spectra at ISR energies, scaled up to the TeV I energy-scale, assuming (quite possibly error-ously) Feyman scaling for the spectra. Note that inclusive Λ and K_s production should be quite accessible as well.

There is already a considerable interest in relating "soft" fragmentation processes to QCD and/or to various Reggeon models. The large energy increase represented by TeV I should be an especially valuable tool in unraveling the physics of these "soft" processes.

In addition the dependence of inclusive beam-fragmentation spectra on any hard collision or other process selected by a DØ central detector is of obvious interest in helping to unravel the basic dynamics.

3) Correlation studies:

Early results from the CERN SPS indicate not only a rather sharply rising multiplicity but also evidence for long-range correlations in rapidity. It is clear that the short-range correlation picture, which is reasonable successful at ISR energies and below, is inadequate to describe all features of the data. Two-particle correlation functions for particles detected within the spectrometer will already be of interest.

The spectrometer will be able to determine the number of charged particles and the number of photons within its acceptance. This may give us some insight into the peculiar Centauro events seen in cosmic rays.

Again, all information on the structure of beam-jet fragmentation should be useful in understanding the dynamics of hard-collision or other phenomena studied by a DØ central detector. Also, correlations between observations in this spectrometer and a second spectrometer (P-709?) in the opposite direction would provide information on correlations between the two fragmentation regions.

4) Inclusive dileptons:

Probably $e^+ e^-$ pairs are the easiest to study, although the problems of beam pipe conversions, etc. may be severe. The apparatus acceptance is good for inclusive Ψ production in momentum range of ~ 20 GeV upward. Probably $\sigma B \lesssim 10^{-31}$ cm^2. For 10^3 ψ's one needs about 6 x 10^8 interactions. Inclusive Υ production lies within the apparatus acceptance and although both the TRD and electromagnetic shower detectors could be used in the trigger, there is an obvious signal/background problem to overcome.

5) Inclusive charm:

Low multiplicity decay products of high-momentum charmed hadrons (p > 150GeV) will, with high probability (>90%/track) lie within the apparatus acceptance. This should allow reasonable studies of central production as well as of diffractive mechanisms provided the signal/background problem can be beaten down, perhaps with fast trigger processing. This is a heavy problem, but may be feasible as a long range goal.

THE SPECTROMETER

The spectrometer (Figure 1) is designed to subtend the forward region of solid angle with detectors which provide good particle spatial resolution, good momentum resolution, and particle identification. It is highly modular in construction so detector elements can be replaced or rearranged to optimize particular and evolving physics goals. Extension of the solid angle coverage to the backward (symmetric) direction or the central region can occur in a natural way.

We choose a multimagnet system for our spectrometer. A minimum of three magnets is required since we must restore the beam in angle as well as position and it seems natural to utilize these magnets in the spectrometer. For a three magnet system the middle magnet must have twice the field integral as the other two. We choose a four magnet system since in this case all of the magnets can be identical and powered in series.

Since almost all types of particle identification require knowledge of the particle momentum, we incorporate good momentum resolution as a cornerstone of this proposal. We emphasize modular particle identification and in particular "non-destructive" identifiers such as transition radiation(TR) where multiple attempts at track identification can be done.

We now describe the relevant parts of the spectrometer.

The Wire Chambers: We believe that wire chambers with effective spatial resolution of 100 microns can be constructed in the rather modest sizes required for this spectrometer. These could be proportional chambers with wire spacing of 0.5 to 1.0 mm used in pairs staggered by 1/2 their wire spacing. Implementation of these chambers in the conventional x, y orthogonal configuration with a u at 45 degrees will give the needed excellent spatial resolution and track separation. Attractive alternatives such as drift chambers which small drift distances (like 3 mm) may offer even better spatial resolution but have somewhat poorer multitrack discrimination. A large system with these capabilities is now being installed at Brookhaven National Laboratory (Platner 1982). The exact geometry of these chambers, and the fact that they must surround the beam pipe, is a problem whose solution must be carefully optimized. However, we believe it feasible to have a detector with 100 micron resolution packaged in a space of 20 cm along the beam direction. We will assume modules with these properties in our spectrometer design.

The Magnets: We use four conventional dipoles for momentum analysis of the secondaries and for the orbit restoration of the colliding beams. These dipoles are identical and have a full aperature of 0.5 x 0.5 m and a length of 1.0 m in the beam direction. We assume a conservative design which will give 15 kG in the above volume. All of the magnets (see Figure 1) will be powered in series and we assume that they would be slowly energized after stored beam is established.

This multiple magnet scheme will in general provide for more than one measurement of a track's momentum. Assuming that the track passes through the chamber station before and after the magnet, the accuracy of each measurement is $\Delta p/p = 0.022\ p$ (%) where p is the track momentum in GeV/c. Thus a 200 GeV/c secondary is measured to a precision of 4.4 %. This precision is slightly less (1.5) for the first magnet since the separation of its upstream PWC's is less than the others.

Particle Identification: Particle identification modules would be about 1 m in length and constructed in such a manner to be removable for testing and reconfiguration. One of the most promising type of identifier utilizes transition radiation (TR) and a cluster counting technique (Fabjan 1981). Figure 4 shows the impressive results achieved by this group in the separation of e/pi at 15 GeV/c and pi/K at 140 GeV/c. This technique would become even more effective at higher momentum. TR modules appropriately optimized for specific particle discrimination, can be made with low mass, good time response, and good multitrack efficiency. As an example, pi/K separation at 140 GeV/c with a separation factor of 100, can be done in a total length of 1.3 m. Figure 1 shows a number of TR detectors optimized for different particle separation. Another low mass compact detector which may be applicable utilizes relativistic rise and is described in Ludlam 1981.

Ring imaging Cerenkov counters may provide another useful particle identification tool. Recent tests in a 200 GeV/c beam at Fermilab (Contrakon, 1981) demonstrated the utility of this technique for pi/K identification; however, lengths in the beam of 5-10 m are required. Detectors utilizing electromagnetic shower identification (lead glass, NaI, etc.) can also be made modular and compact. While these are destructive identification techniques, they are appropriate as "facing" for the magnet yokes and at the end of the spectrometer as shown in Figure 1. These would be appropriate for both electron and photon identification.

Geography: Approximately 25 m is available on either side of the D0 interaction region before one encounters cryogenic components of the doubler or magnets of the conventional main ring. We constrain our spectrometer to fit into this distance. Since the beam line of the doubler (Figure 5) is only 10.5 inches above the tunnel floor, a considerably smaller distance than the 25.5 inches from the doubler beam to the present main ring, we are asking that the floor be excavated to allow for about as much room below the collision point as above it.

OTHER CONSIDERATIONS: Luminosity, Triggering, Backgrounds, and Is This Really a Proposal?

There are evidently many issues not covered in detail in this document, e.g.

Luminosity: This spectrometer will be already very useful for an early survey of particle production for any luminosity greater than 10^{25} cm^{-2} sec^{-1}. Therefore low $-\beta$ is not a necessary desideratum. There do exist schemes for attaining β^* of $\lesssim$ 5-10 m while still leaving free space of $\pm$ 25 m around the interaction point.

Triggering: It is premature to consider triggering schemes. Positive evidence of beam-beam collisions requires detectors in the phase space not covered by the forward spectrometer. This in turn requires knowledge of what apparatus will exist for looking at large-angle phenomena.

Backgrounds: Backgrounds from secondaries interacting in the apparatus may be estimated from experience in similar fixed-target environments inasmuch as the laboratory energies and multiplicities are comparable (albeit somewhat lower). Interactions and photon conversions in the beam-pipe pose an additional special problem, requiring care in design.

Manpower: The manpower represented by the names on this proposal scarcely suffices for mounting such an enterprise. However we feel that the physics which this spectrometer explores is quite sizeable, with considerable long range potential. We believe it important that the Laboratory and its Program Committee should consider it carefully while formulating its plans for development of the DØ collision region.

References

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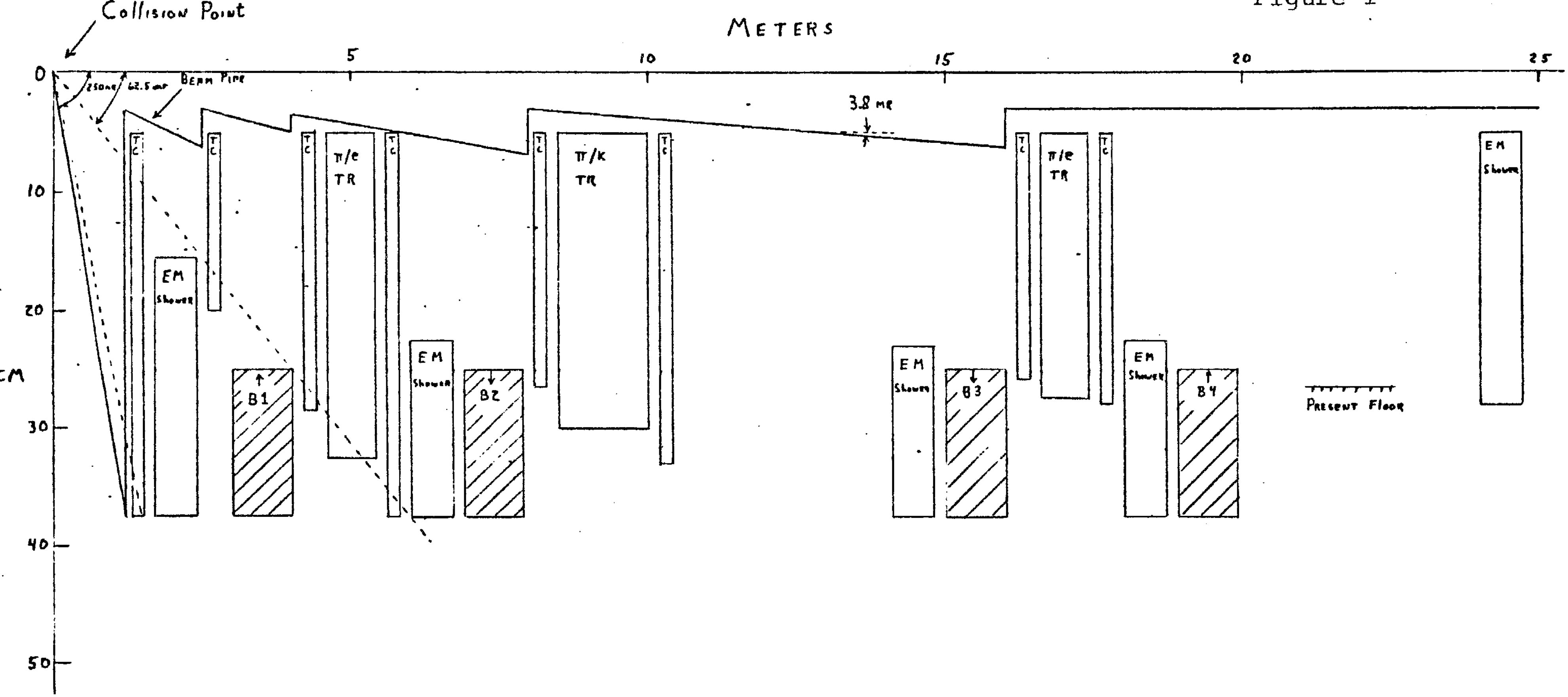
Goodman, J. A. et al. 1979. Phys. Rev. Lett. 42:854.
Fabjan, C. W. et al, 1981. Nucl. Instr. and Meth. 185:119.
Ludlam, T. et al, 1981. IEEE Trans. Nucl. Sci. NS-28:439.
Platner, E. D. 1982. Brookhaven National Laboratory HEDGE Newsletter. January 1982.

Figure 1

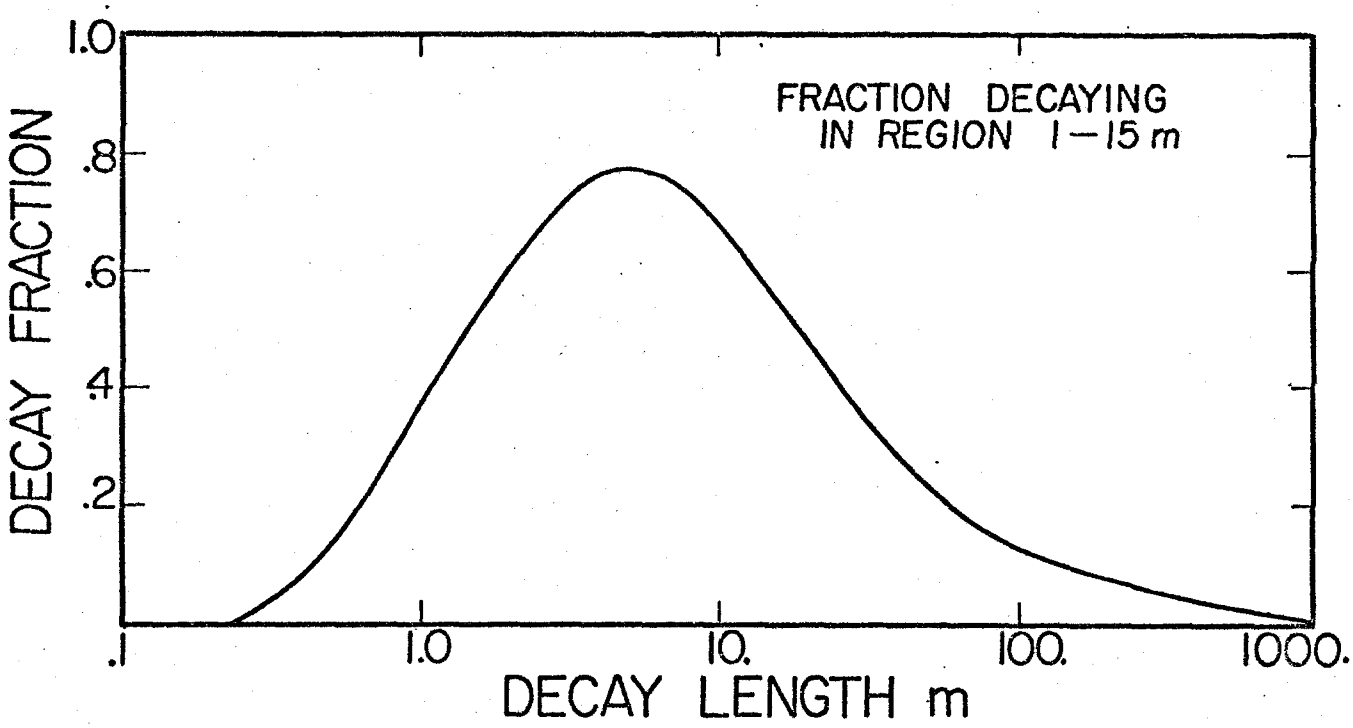


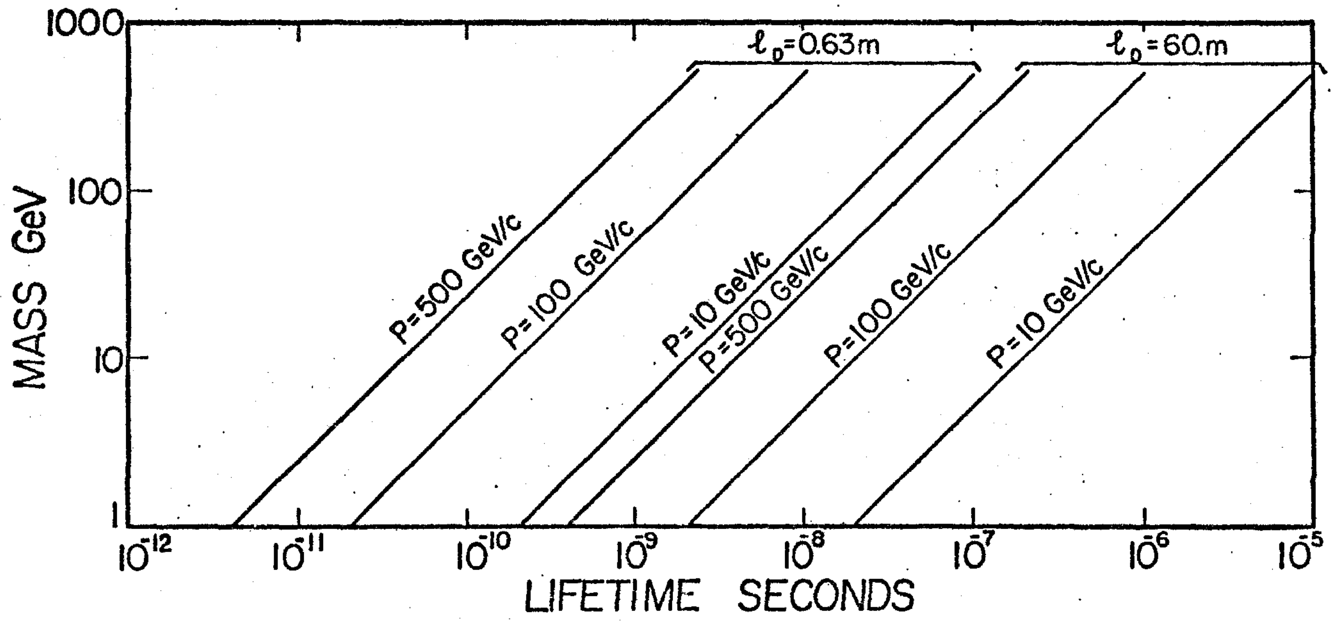
FORWARD LOOKING SPECTROMETER

Sample Configuration

TC = Tracking chambers EM = Electromagnetic shower counter TR = Transition radiator detector

B1, B2, B3, B4 are spectrometer dipole magnets





Top Figure: Fraction of particles which will decay in a region between 1-15 m from primary vertex as a function of decay length.

Bottom Figure: For two different decay lengths (0.63 and 60. m), corresponding to decay fractions of 0.20 in top figure, we plot mass versus lifetime for various values of momentum.

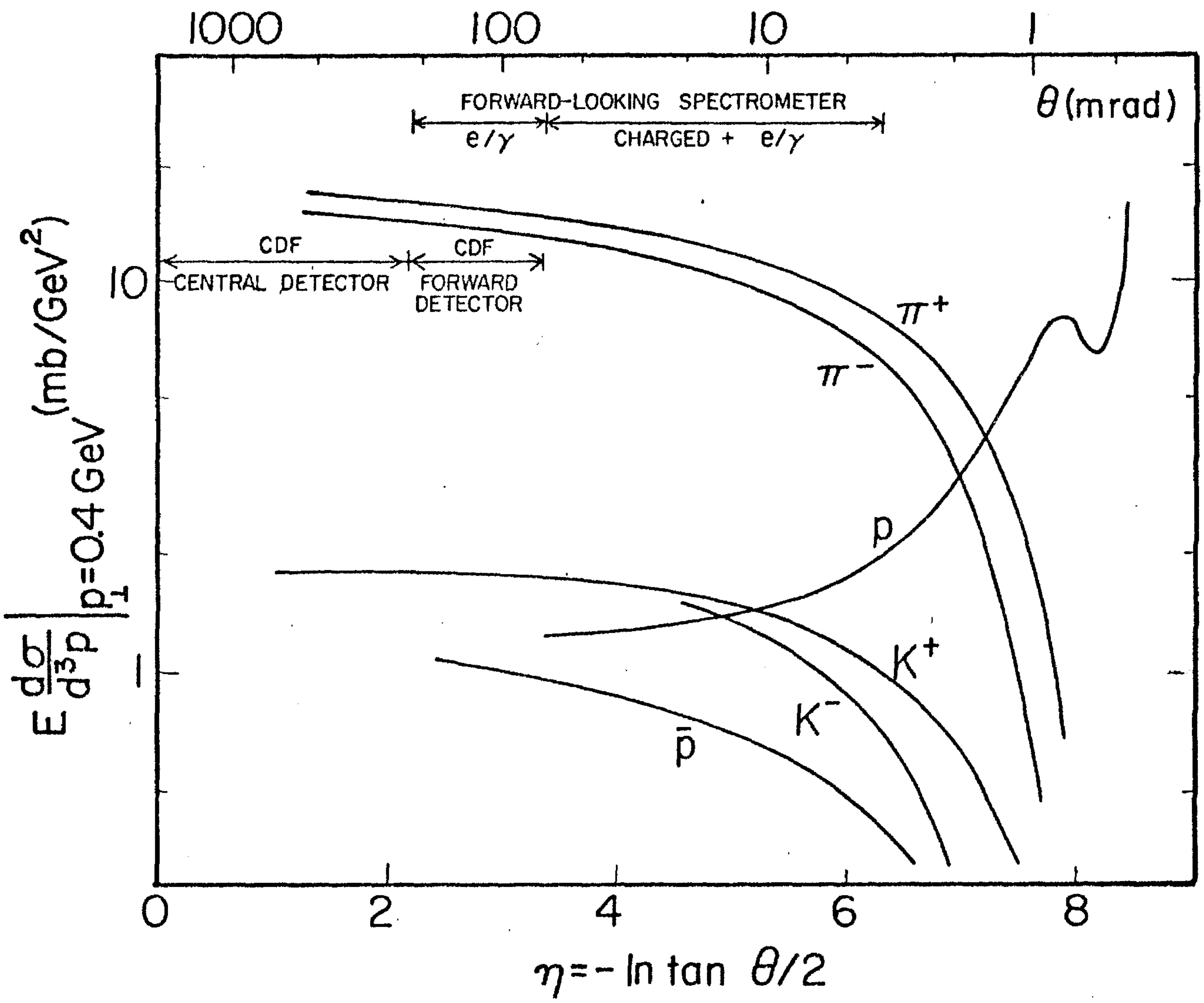


Figure 3a: Comparison of inclusive spectrum coverage of CDF and Forward-Looking Spectrometer.

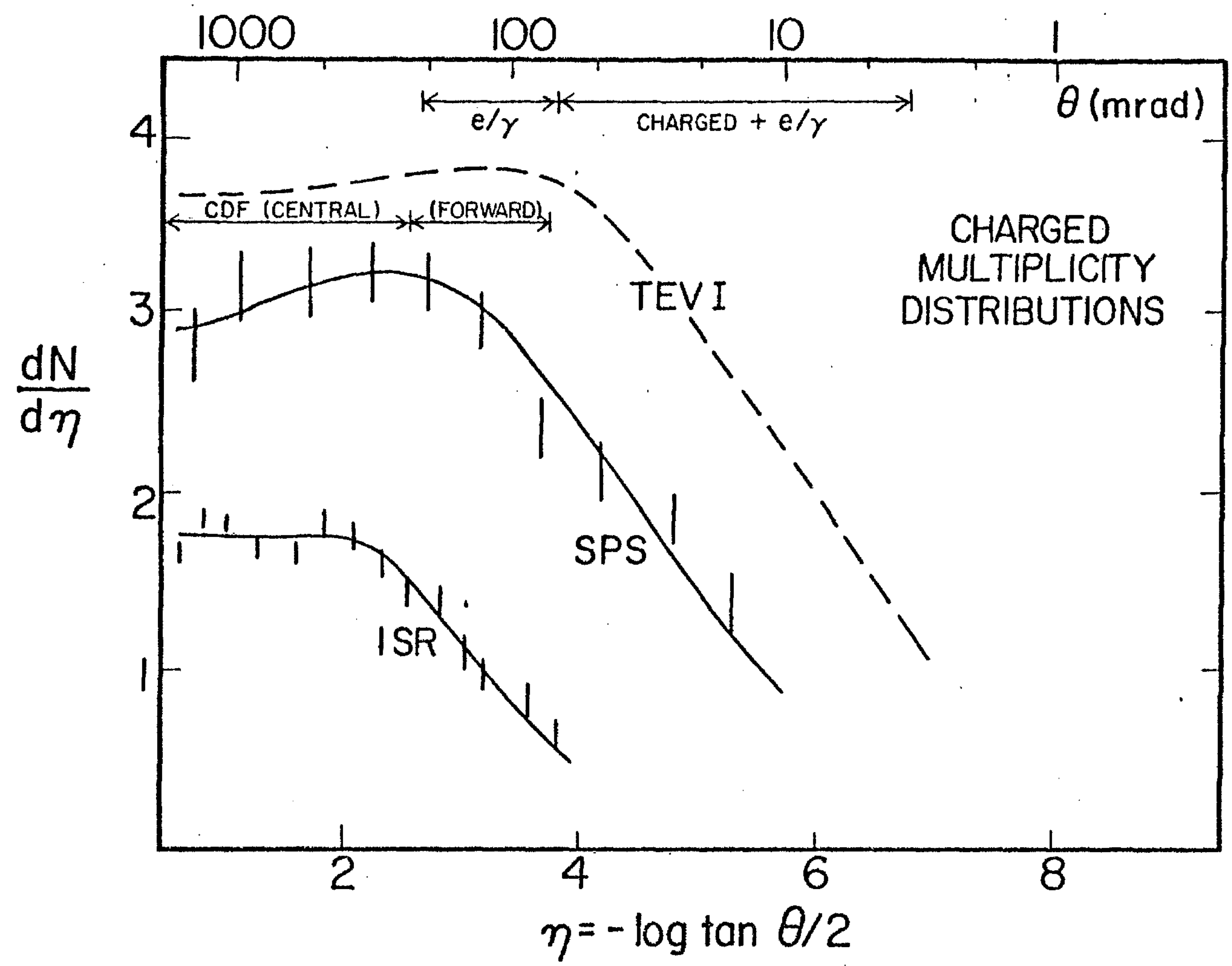
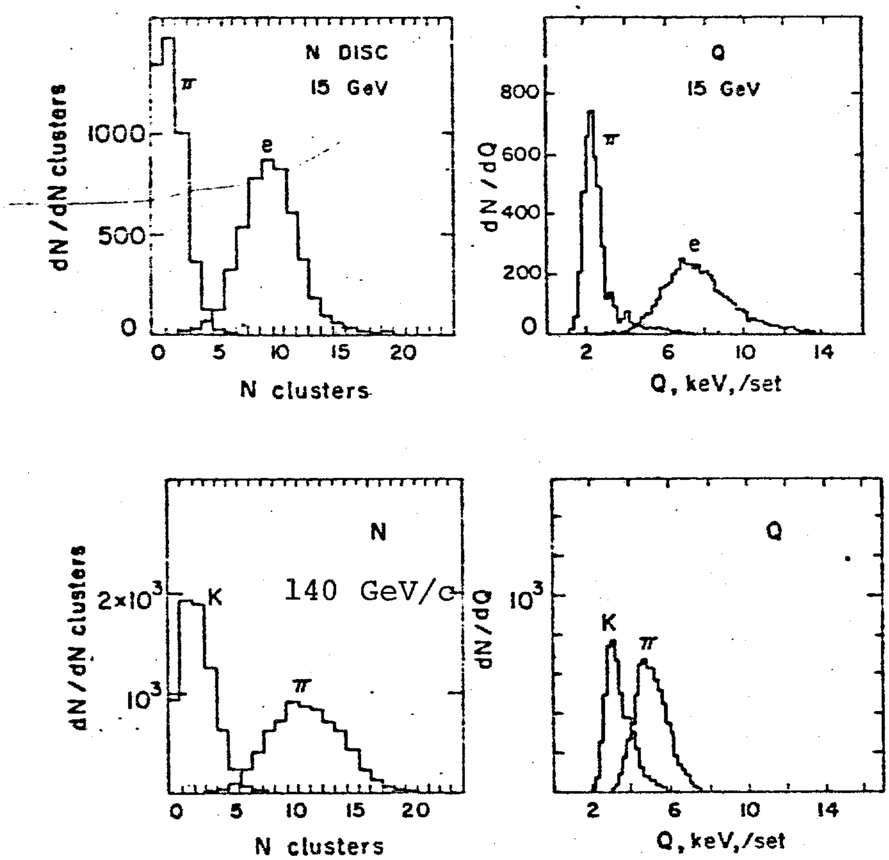
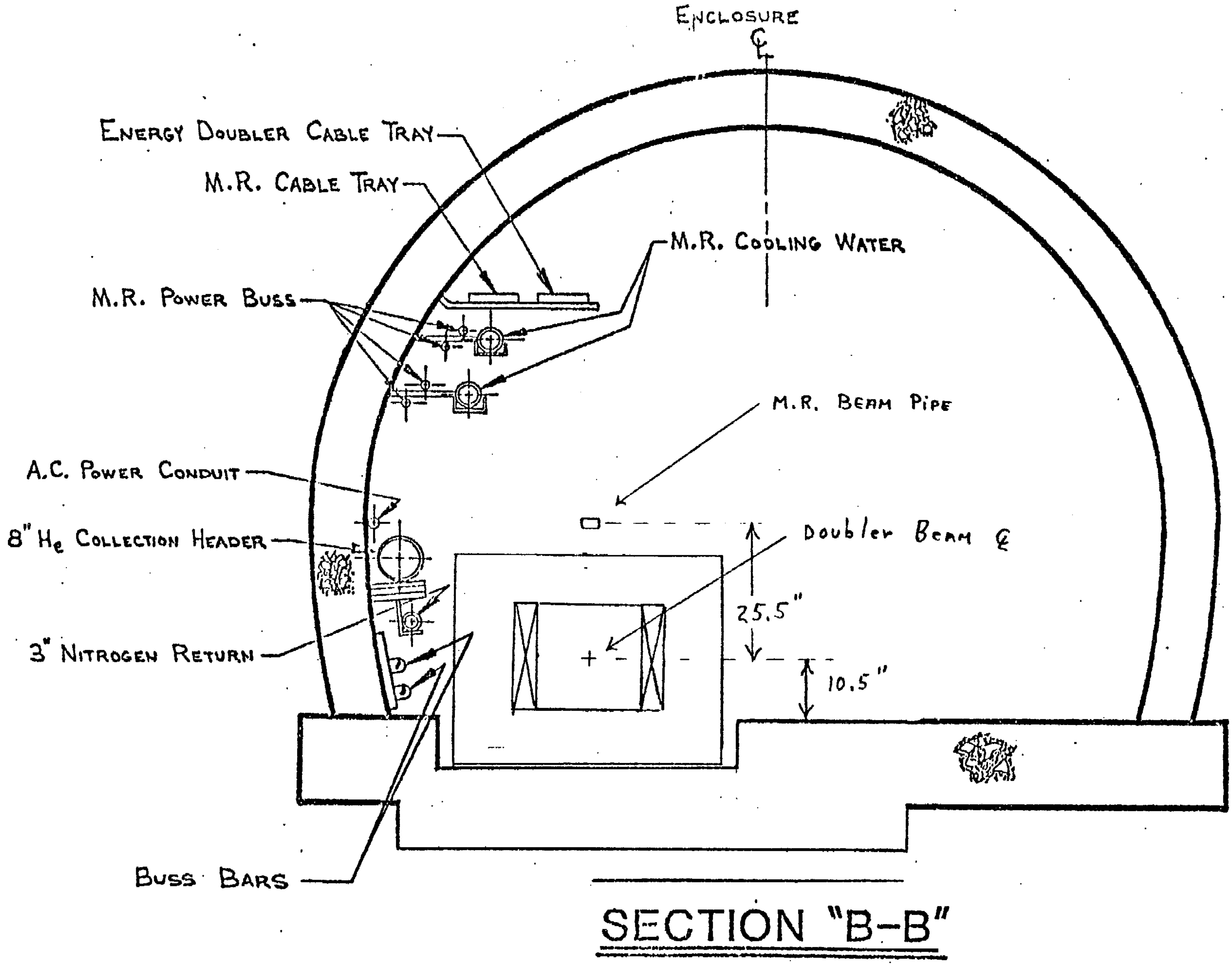


Figure 3b: Multiplicity scaled to TeV I energy and comparison of CDF and Forward-Looking spectrometer coverage.



A comparison of track identification using transition radiation and the cluster counting method (N) and measuring the total ionization (Q). The upper figures are for pi/e separation at 15 GeV/c and the lower for pi/K separation at 140 GeV/c. These are taken from Fabjan 1981.

Figure 5



Configuration of magnets in accelerator tunnel